HYDRAULIC RESEARCH

August 22, 1975

National Aeronautics & Space Administration
George C. Marshall Space Flight Center
Huntsville, Alabama 35812

FINAL SUMMARY REPORT

SSME-HAS

DYNAMIC LOAD SIMULATORS

(NASA-CR-143984) SSME-HAS DYNAMIC LOAD SIMULATORS Final Summary Report (Hydraulic Research and Mfg. Co.) 22 p HC $3.25 CSCL 14B

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FINAL SUMMARY REPORT

SSME-HAS

DYNAMIC LOAD SIMULATORS

MPVA Load Fixture - Part No. T34000280-1-61

PVA Load Fixture - Part No. T34000290-1-68

Prepared for George C. Marshall Space Flight Center

NASA, Marshall Space Flight Center, Ala.

PREPARED BY J. E. Hongaster DATE Aug 19, 1975
CHECKED BY DATE
APPROVED BY R. Kittmeyer DATE Aug. 21, 1975
APPROVED BY [illegible] DATE Aug 21, 1975
APPROVED BY DATE

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1.0 SUMMARY OF ACCOMPLISHMENTS

Hydraulic Research and Manufacturing Company was awarded contract No. NAS 8-30893 on June 3, 1974, to design, develop, fabricate, test and deliver five load fixture assemblies for laboratory system testing of the Five Space Shuttle Main Engine (SSME) Propellant Valve Actuators. In addition, HR & M Co. agreed to deliver a preburner valve actuator (PVA) that was referred to in the contract as "an alignment fixture to permit precise adjustment of the load simulator mechanical interface."

The five dynamic load simulators are designed to simulate the loads reflected into the SSME Hydraulic Actuators by the Chamber Coolant Valve (CCV), the Fuel Preburner Oxidizer Valve (FPOV), the Oxidizer Preburner Oxidizer Valve (OPOV), the Main Oxidizer Valve (MOV) and the Main Fuel Valve (MFV). And they are similar to the actual load fixtures used for acceptance testing of the SSME Hydraulic Actuators.

Late in October, 1974, HR & M Co. completed mechanical drawings of the Load Simulators and forwarded them to NASA-MSFC for design review and approval. Comments and design approval were received from NASA-MSFC in the middle of November, 1974 and the next four weeks saw design and fabrication proceeding at a pace consistent with the scheduled delivery date of March 3, 1975.

However, in the middle of December, 1974, Hydraulic Research & Mfg. Co. suffered a labor dispute and all work was stopped for the duration of the dispute. Supplemental agreement No. 2, executed March 3, 1975, extended the contract delivery date to July 3, 1975.

After settlement of the labor dispute, HR & M Co. continued fabrication of the five load simulators and an electronic load system that, with inputs of valve differential pressure ($\Delta P_{(t)}$) and valve inlet pressure ($P_{(t)}$), supplied by NASA, would accurately simulate the loads reflected into each SSME Hydraulic Actuator by its respective valve.

During the period of June 9 through June 13, 1975, Mr. John Glazner of NASA witnessed acceptance tests of the five load simulators in the Engineer Development Lab at HR & M Co. and conditionally accepted them on June 13, 1975, subject to an

acceptable system functional demonstration in the Hydraulic Simulation Laboratory at Marshall Space Flight Center.

The Five Load Simulators and the Electronic Load System together with the PVA alignment fixture were shipped air freight to NASA-MSFC on June 20, 1975.

2.0 DESIGN AND FUNCTIONAL DESCRIPTION

2.1 General

The design and function of the five load simulators is the same as that of the SSME-HAS Load Fixtures used for acceptance testing of the SSME Hydraulic Actuators at HR & M Co. A complete functional and operational description of the Load Fixtures is presented in the operation manual (HR No. 79700012).

2.2 Mechanical

Each of the load fixtures simulates flow torque by applying hydraulic pressure through a three-stage servovalve to a push-push piston-crankshaft assembly.

Reference Drawing No. T34000280-1-61 and T34000290-1-68.

2.3 Electronics

The electronic control circuits are divided into two sections.

One, the servoamplifier which multiplies the flow torque command from the NOVA 1210 computer with the $\Delta P_{(t)}$ valve from NASA and sums this valve with crankshaft linkage multiplied by feedback ΔP.

Two, the friction scaling amplifier solves the friction equation and sums that value with the $P_{(t)}$ and $\Delta P_{(t)}$ values supplied by NASA.

The servoamplifier and friction scaling amplifier signals are summed together to apply the proper drive signal to the servovalve.

3.0 DOCUMENTS AND DRAWINGS

A complete set of detailed drawings have been submitted in compliance with the Data Requirements List No. 433.

LIST OF DRAWINGS

Mechanical

Main Propellant Valve Actuator (MPVA) Load Fixture

T34000280-1-61	Load Fixture Assembly (MPVA)
T34000280-1-2	Housing, Adapter
T34000280-1-59	Shaft, Torque
T34000280-1-37	Flywheel
T34000290-1-5	End Cap, Housing
T34000290-1-16-2	Cover, Piston
T34000290-1-71	Pulley, Transducer (External)
T34000280-1-40	Spacer, Splined
T34000280-1-10	Washer, Thrust
T34000290-1-19	Cam, Calibration
T34000290-1-20	Arm, Calibration
T34000290-1-18	Clamp, Cable
T34000280-1-41	Washer
T34000280-1-7	Pulley, Take-off
T34000280-1-23	Bracket, Mounting
T34000280-1-24	Lug, Mounting
T34000290-1-75	Cover, Encoder
T34000280-1-22	Baseplate
T34000290-1-42	Assembly, Tube
T34000280-1-38	Screw, Shoulder
T34000290-1-17	Washer, Bellville Backup
T34000290-1-62	Screw, Shoulder
T34000290-1-65	Housing and Piston Assembly
T34000290-1-92	Housing, Piston
T34000290-1-43	Piston
T34000290-1-63	Rod Assembly, Piston
T34000260	Valve, Hydraulic Servo
T34000260-2	Housing Assembly
T34000260-3	Spool, Sleeve Assembly
T34000260-5	Cap, Adjuster
T34000260-7	Spool
T34000260-8	Sleeve
T34000260-9	Insert
T34000260-10	Sleeve Assembly
T34000260-11	Adapter Plate
T34000280-1-29	Calibration Tool
T34000280-1-30	Body
T34000280-1-31	Spud

T34000280-1-32	Insert
T34000280-1-33	Handle
T34000280-1-34	Detent
T34000280-1-35	Stop Plate
T34000280-1-36	Spacer
22252380	Servovalve, Two Stage, 4-Way
T34000290-1-81	Hydraulic Schematic, Load Fixture

Preburner Valve Actuator (PVA) Load Fixture

T34000290-1-68	Load Fixture Assembly (PVA)
T34000290-1-2	Housing, Adapter
T34000290-1-67	Shaft, Torque
T34000290-1-37	Flywheel
T34000290-1-5	End Cap, Housing
T34000290-1-16-2	Cover, Piston
T34000290-1-71	Pulley Transducer, External
T34000290-1-70	Nut, Jam
T34000290-1-17	Washer, Bellville Backup
T34000290-1-18	Clamp Cable
T34000290-1-19	Cam, Calibration
T34000290-1-20	Arm, Calibration
T34000280-1-41	Washer
T34000290-1-80	Washer
T34000280-1-7	Pulley, Takeoff
T34000280-1-22	Baseplate
T34000280-1-23	Bracket, Mounting
T34000280-1-24	Lug, Mounting
T34000280-1-25	Cover, Encoder
T34000290-1-42	Tube Assembly
T34000290-1-62	Screw, Shoulder
T34000290-1-65	Housing and Piston Assembly
T34000290-1-92	Housing, Piston
T34000290-1-43	Piston
T34000290-1-63	Rod Assembly, Piston
T34000290-1-29	Calibration Tool
T34000290-1-30	Body
T34000290-1-31	Spud
T34000290-1-32	Handle
T34000290-1-33	Insert
T34000290-1-34	Detent
T3400290-1-35	Stop Plate
T34000290-1-36	Spacer
T34000260	Valve, Hydraulic Servo

T34000260-2	Housing Assembly
T34000260-3	Spool, Sleeve Assembly
T34000260-5	Cap, Adjuster
T34000260-7	Spool
T34000260-8	Sleeve
T34000260-9	Insert
T34000260-10	Sleeve Assembly
T34000260-11	Adapter Plate
22252380	Servovalve, Two Stage, 4-Way
T34000290-1-81	Hydraulic Schematic, Load Fixture
T34000721	Ring, Internal Spline
T34000722	Disc, Brake
T34000724	Arm, Sine Bar
T34000740	Ring and Arm Assembly (PVA)
T34000770	Ring and Arm Assembly (MPVA)

<u>Electrical</u>

Load Control System

34010290-001	Load Control System Assembly
34020290-002	Chassis Assembly, Servo Amplifier, Dual
34020290-003	Chassis Assembly, Servo Amplifier, Single
34020290-011	Chassis Assembly, Interface Cards
34020290-012	Chassis Assembly, 10V and 15V Power Supply
34020290-013	Chassis Assembly, 5V Power Supply
34030290-001	Block Diagram, Load Control System
34030290-002	Schematic, Servo Amplifier
34030290-004	Schematic, Friction Scaling
34030290-005	Schematic, Friction Scaling Direction Inverter, Dual
34030290-006	Schematic, Friction Scaling Direction Inverter, Single
34030290-007	Schematic, CPU Termination
34030290-008	Schematic, Encoder Analog Converter
34030290-009	Logic Diagram, Encoder Read Registers
34030290-010	Logic Diagram, DAC Hold Registers
34040290-002	P.C. Board, Drilling, Servo Amplifier
34040290-004	P.C. Board, Drilling, Friction Scaling
34050290-002	Card Assembly, Servo Amplifier
34050290-004	Card Assembly, Friction Scaling
34050290-005	Card Assembly, Friction Scaling Direction Inverter, Dual

34050290-006	Card Assembly, Friction Scaling Direction Inverter, Single
34050290-007	Card Assembly, CPU Termination
34050290-008	Card Assembly, Encoder Analog Converter
34050290-009	Card Assembly, Encoder Read Registers
34050290-010	Card Assembly, DAC Hold Registers
34060290-002	Wiring Diagram, Servo Amplifier, Dual
34060290-003	Wiring Diagram, Servo Amplifier, Single
34070290-012	Wiring Diagram, Power Supply Harness
34080290-001	Cable Assembly, Nova 1210 CPU
34080290-002	Cable Assembly, Servo Amplifier, Dual
34080290-003	Cable Assembly, Servo Amplifier, Single
34080290-004	Cable Assembly, Pressure Transducer
34080290-005	Cable Assembly, Servovalve
34080290-006	Cable Assembly, Encoder Reader, Nos. 1 & 2
34080290-007	Cable Assembly, Encoder Reader, Nos. 3 & 4
34080290-008	Cable Assembly, Encoder Reader, No. 5
34090650-002	Wire List, Load System Termination
34090290-008	Wire List, Encoder Analog Converter
34090290-009	Wire List, Encoder Read Registers
34090290-010	Wire List, DAC Hold Registers
34090290-011	Wire List, Card Chassis Backplane
34100290-011	Pin Layout, I/O Connector, Card Chassis
PL34050290-002	Parts List, Servo Amplifier Card Assembly
PL34050290-004	Parts List, Friction Scaling Card Assembly

4.0 CALCULATIONS

4.1 Load Fixture Control Transform

The control transform uses known parameters to determine the servovalve pressure drop corresponding to the required torque. The control transform is used (via computer) to set this servovalve pressure drop during actuator testing. The load fixture provides a shaft torque for a specific shaft angle. A schematic of the load fixture showing pertinent geometric parameters is shown in Figure 1.

Three equations which, when combines, will yield shaft torque are:

1) $T = P_1L_1A_1 - P_2L_2A_2 = (P_1L_1 - P_2L_2)A$

where T = shaft torque (in-lb)

P_1 = pressure in chamber #1 (psi)

P_2 = pressure in chamber #2 (psi)

L_1 = effective lever arm #1 (in)

L_2 = effective lever arm #2 (in)

$A_1=A_2=A$ = cylinder bore cross-sectional area (in^2)

2. $\Delta P = P_1 - P_2$

where ΔP = pressure difference between chambers #1 and #2

3. $P_S - P_R = P_1 + P_2$

where P_S = servovalve supply pressure

P_R = servovalve return pressure

Combining equations 2 and 3

4. $$P_1 = \frac{\Delta P + P_S - P_R}{2}$$

5. $$P_2 = \frac{P_S - P_R - \quad P}{2}$$

Combining equations 4 and 5 with 1

6. $$\Delta P = \frac{2T}{A} - (P_S - P_R)(L_1 - L_2)\ \frac{1}{L_1 + L_2}$$

Thus when required torque (T), cylinder bore area (A), load fixture servovalve pressure drop ($P_S - P_R$) and effective lever arm lengths (L_1 and L_2) are known the required differential between chambers #1 and #2 can be determined.

As may be noted in Figure 1, the effective lever arm length varies with shaft angle. The program which calculates the effective lever arm versus shaft angle is presented, Figure 2, and a plot

of load fixture effective lever arm versus shaft angle is presented in Figure 3.

For computer use it is advantageous for the curve shown in Figure 3 to be an equation. A program was written which utilizes software provided by the time-share vendor (General Electric Information Services) to generate the constant coefficients of the polynomial.* The program generates the constant coefficients (A_i) for the equation:

$$y = \sum_{i=1}^{9} A_i x^{i-1}$$

4.2 Friction Torque Calculations

The friction torque (in-lb) was determined by the following equations:

Chamber Coolant Valve (CCV)
$f_{(t)} = 35.6 + .01\ \Delta P_{(t)} + .047\ P_{(t)}$

Fuel Preburner Oxidizer Valve (FPOV)
$f_{(t)} = 42.5 + .01\ \Delta P_{(t)} + .047\ P_{(t)}$

Oxidizer Preburner Oxidizer Valve (OPOV)
$f_{(t)} = 42.5 + .01\ \Delta P_{(t)} + .047\ P_{(t)}$

Main Oxidizer Valve (MOV)
$f_{(t)} = 111.4 + .01\ \Delta P_{(t)} + .047\ P_{(t)}$

Main Fuel Valve (MFV)
$f_{(t)} = 111.4 + .01\ \Delta P_{(t)} + .047\ P_{(t)}$

Where $\Delta P_{(t)}$ (lb/in^2) is the pressure differential across the engine valve and $P_{(t)}$ (lb/in^2) is the hydraulic pressure at the inlet to the valve.

4.3 Flow Torque Calculations

The flow torque (in/lb) was defined by the following general equations:

*Least-squares or min-max fit of a linear curve.

$$T_{(t)} = \frac{Kc\theta\,[G\ Ae\theta\ Y\sqrt{\Delta P_{(t)}}]^2}{\rho\, d_H}$$

Where $Kc\theta$ is the torque coefficient; tabulated values are presented in Table 1 of Attachment I.

$Ae\theta$ is the effective valve area defined by the curves in Figures 1, 2, 3, 4 and 5 of Attachment I.

ρ is the fluid density and is 4.6 lb/ft^3 for helium and 71.0 lb/ft^3 for oxygen.

d_H is the valve hole diameter and is as follows:

CCV = 1.6 in.

FPOV = OPOV = 1.1 in.

MOV = MFV = 2.5 in.

G, the orifice coefficient is as follows:

$G_{ccv} = 1.44$

$G_{fpov} = 5.80$

$G_{opov} = 8.16$

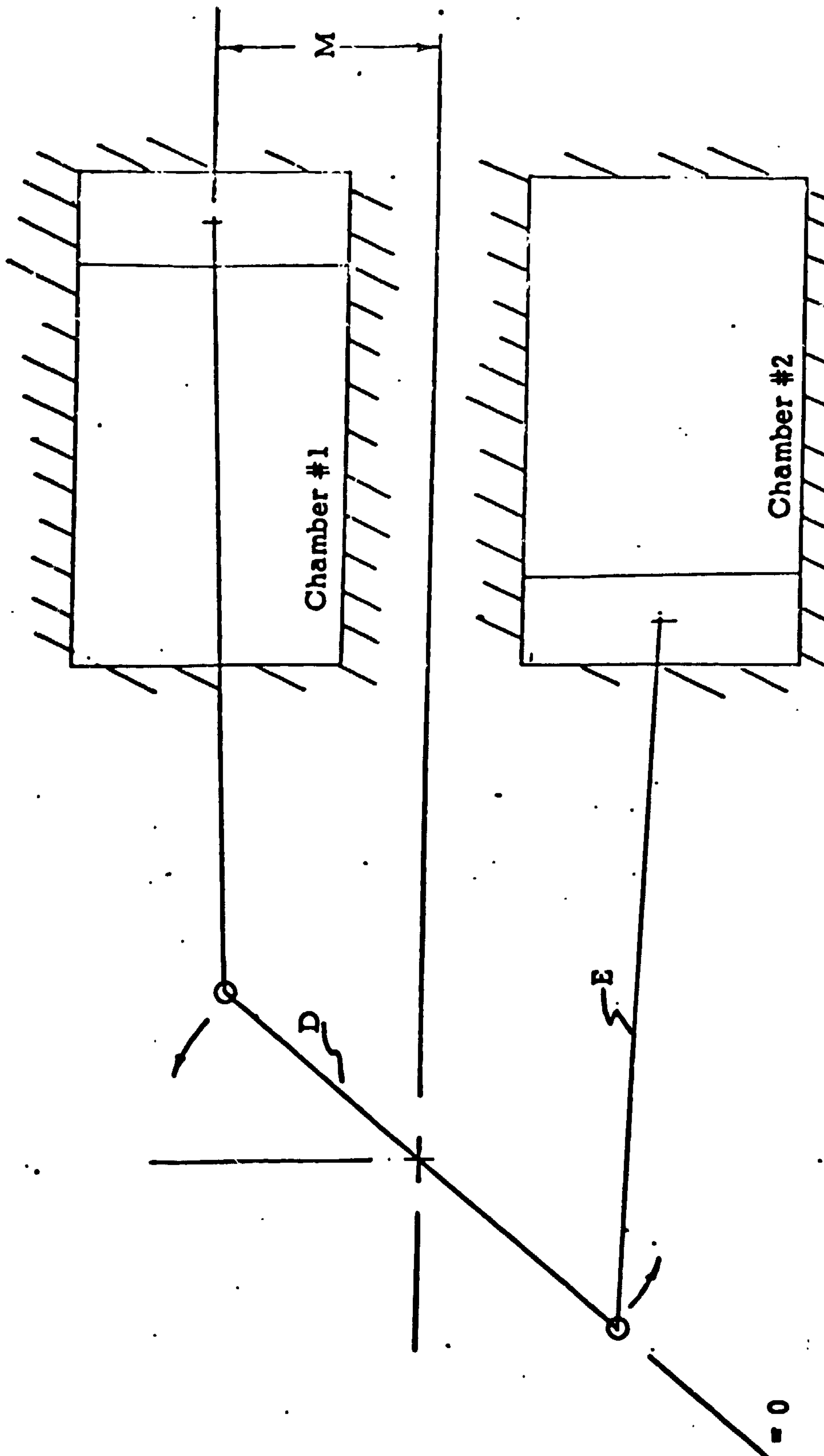
$G_{mov} = 5.64$

$G_{mfv} = 1.52$

$\Delta P_{(t)}$ and $P_{(t)}$ are the same as in paragraph ..2.

5.0 STATEMENT OF CONFORMANCE

The acceptance tests performed at HR & M Co. June 9 through June 13, 1975 and witnessed by Mr. John Glazner of NASA-MSFC satisfactorily determined that the Dynamic Load Simulators/Load Control System has the capability to verify the propellant control system performance. Further, the SSME-HAS simulators will verify minimum and maximum engine thrust level loads as well as engine start, stop and emergency shutdown transients loads. See Attachment II.



where D = 1.4375 inch
E = 3.875 inch
M = 1.25 inch

Figure 1 Load Fixture Schematic

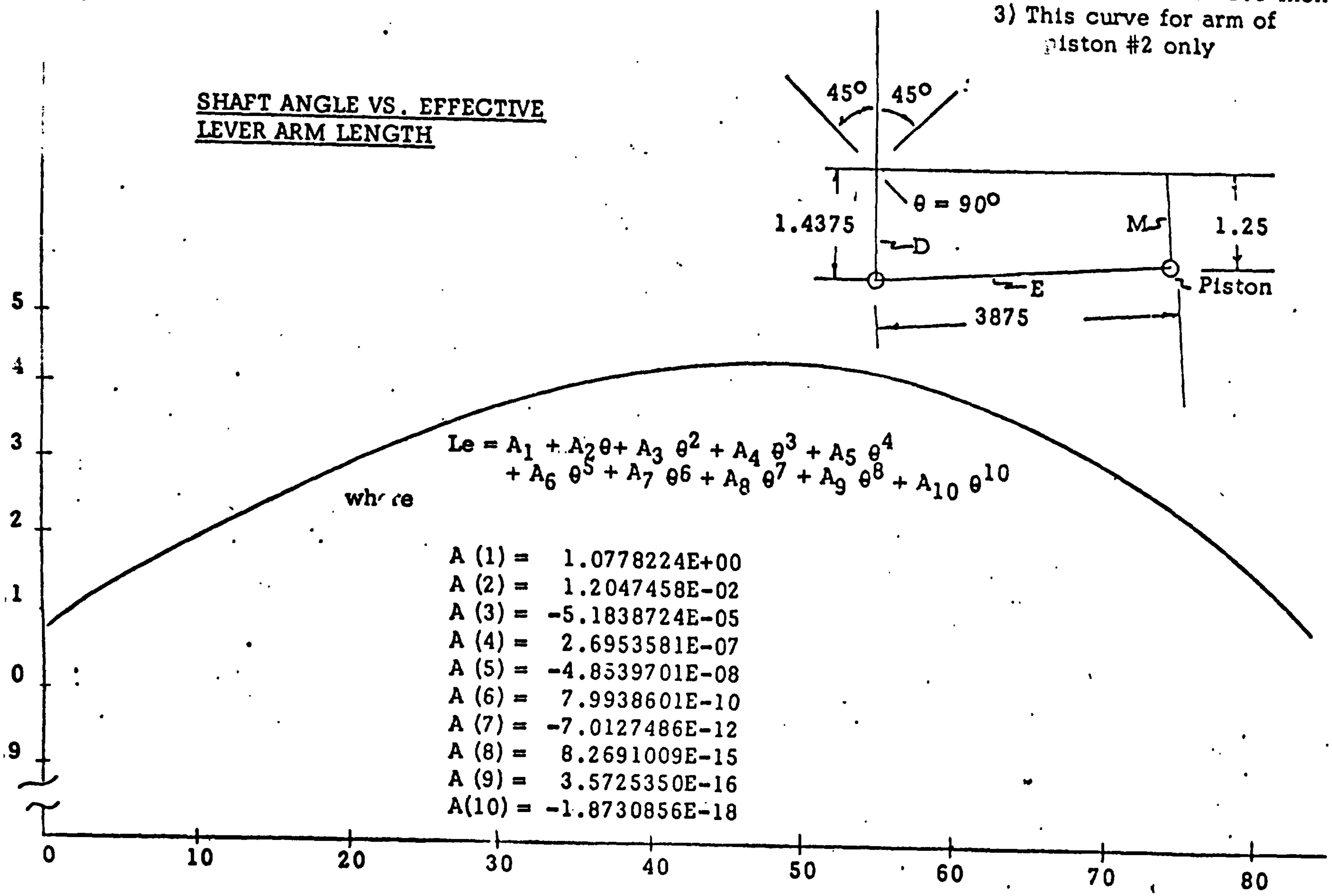
ARM 01/18/74

```
 90 REAL LEFF, L, M, L1, L2
100 DIMENSION Y (40)
110 TP = 1.
115 4 FORMAT (V)
120 PRINT, "D,M,E"
130 INPUT,D,M,E
140 L1=M-D*COS (45./57.3)
150 L2=SORT(E**2-L1**2)
160 L=L2-D*SIN(45./57.3)
170 PRINT,"L=",L
180 S=L2+D*SIN(45./57.3)-L
190 PRINT,"S=",S
200 CGO=(D**2+L**2+M**2-E**2)/(2.*D*SQRT(L**2+M**2))
210 SGO=SQRT(1.-CGO**2)
220 GAMO=ATAN2(SGO,CGO)
230 DX=5/40.
240 DO 1 I=1,42
250 XP=XP+DX
260 IF(I.EQ.1) XP=0.
270 IF(I.EQ.42) XP=S
280 CG=(D**2+(L+XP)**2+M**2-E**2)/(2.*D*SQRT((L+XP)**2+M**2))
290 SG=SQRT(1.-CG**2)
300 GAM=ATAN2(SG,CG)
310 BEO=ATAN(M/L)
320 BE=ATAN(M/(L+XP))
330 PI=3.14159
340 AO=PI-GAMO-BEO
350 A=PI-GAM-BE
360 THETA=(A-AO)&57.3
370 TD=(D*SIN(A)-M)/(D*COS(A)+L+YP)
380 FX=TP/(D*SIN(A)-D*TD*COS(A))
390 LEFF=TP/FX
395 WRITE("LDCURV",4)LEFF,THETA
400 PRINT,"L EFFECTIVE=",LEFF,"  ","THETA=",THETA,"XP=",XP
402 1 CONTINUE
410 STOP;END
```

Figure 2 Program to Determine Effective Torque Arm

Note: 1) Crank shown in 45° position
2) Piston Diameter 1.5 inch
3) This curve for arm of piston #2 only

SHAFT ANGLE VS. EFFECTIVE LEVER ARM LENGTH



$$Le = A_1 + A_2\theta + A_3\theta^2 + A_4\theta^3 + A_5\theta^4 + A_6\theta^5 + A_7\theta^6 + A_8\theta^7 + A_9\theta^8 + A_{10}\theta^{10}$$

where

A (1) = 1.0778224E+00
A (2) = 1.2047458E-02
A (3) = -5.1838724E-05
A (4) = 2.6953581E-07
A (5) = -4.8539701E-08
A (6) = 7.9938601E-10
A (7) = -7.0127486E-12
A (8) = 8.2691009E-15
A (9) = 3.5725350E-16
A(10) = -1.8730856E-18

θ. SHAFT ANGLE - DEG.

Figure 3

ATTACHMENT I

TABLE I

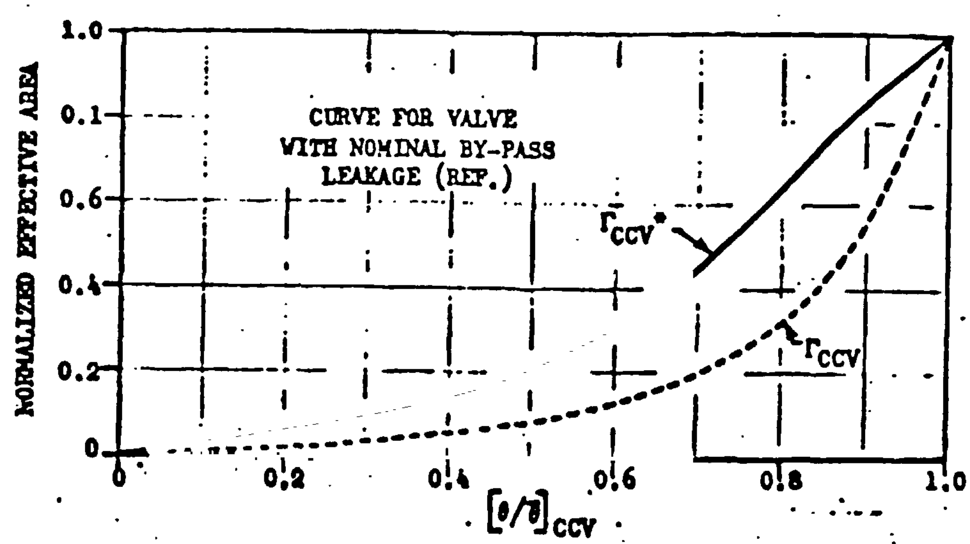
TABLE VII

ENGINE CONTROL VALVE HYDRAULIC TORQUE COEFFICIENTS

MOV		MFV		OPV		FPV		CCV	
[θ/θ̄]	[K_c]	[θ/δ]	[K_c]	[θ/δ]	[K_c]	[θ/δ]	[K_c]	[θ/δ]	[K_c]
1.0000	0.000	1.0000	0.000	1.0000	0.000	1.0000	0.000	1.0000	0.000
0.9706	0.441	0.9706	0.441	0.9687	1.388	0.9687	0.661	0.9687	0.279
0.9412	1.013	0.9412	1.013	0.9375	2.465	0.9375	1.407	0.9375	0.643
0.9118	1.514	0.9115	1.514	0.9062	3.191	0.9062	1.924	0.9062	1.044
0.8824	1.894	0.8824	1.894	0.8750	3.510	0.8750	2.196	0.8750	1.401
0.8529	2.089	0.8529	2.089	0.8437	3.349	0.8437	2.515	0.8437	1.719
0.8235	2.309	0.8235	2.309	0.8125	3.883	0.8125	2.973	0.8125	1.934
0.7941	2.557	0.7941	2.557	0.7812	4.833	0.7812	3.610	0.7812	2.072
0.7647	2.925	0.7647	2.925	0.7500	5.926	0.7500	4.507	0.7500	2.224
0.7353	3.361	0.7353	3.361	0.7187	7.197	0.7187	5.800	0.7187	2.390
0.7059	3.900	0.7059	3.900	0.6875	8.695	0.6875	8.137	0.6875	2.580
0.6765	4.642	0.6765	4.642	0.6562	10.484	0.6562	8.221	0.6562	2.891
0.6471	5.612	0.6471	5.612	0.6250	12.648	0.6250	10.791	0.6250	3.155
0.6176	6.903	0.6176	6.903	0.5937	15.292	0.5937	14.382	0.5937	3.509
0.5882	7.270	0.5882	7.150	0.5625	18.509	0.5625	19.432	0.5625	3.933
0.5588	8.898	0.5588	8.720	0.5312	22.183	0.5312	26.059	0.5312	4.467
0.5294	10.997	0.5294	10.728	0.5000	24.748	0.5000	30.746	0.5000	5.145
0.5000	13.765	0.5000	13.344	0.4687	12.683	0.4687	12.754	0.4687	5.931
0.4706	17.499	0.4706	16.312	0.4563	0.000	0.4563	0.000	0.4375	6.982
0.4412	22.630	0.4412	21.449					0.4062	6.995
0.4118	23.657	0.4118	27.508					0.3750	8.073
0.3824	30.356	0.3824	34.274					0.3437	9.362
0.3529	42.739	0.3529	35.649					0.3125	10.925
0.3235	14.734	0.3235	10.966					0.2812	12.844
0.3130	0.000	0.3130	0.000					0.2500	15.232
								0.2187	18.244
								0.1875	22.082
								0.1562	26.975
								0.1250	33.025
								0.0937	39.538
								0.0625	42.402
								0.0312	27.559
								0.0052	0.000

ATTACHMENT I

Figure 1



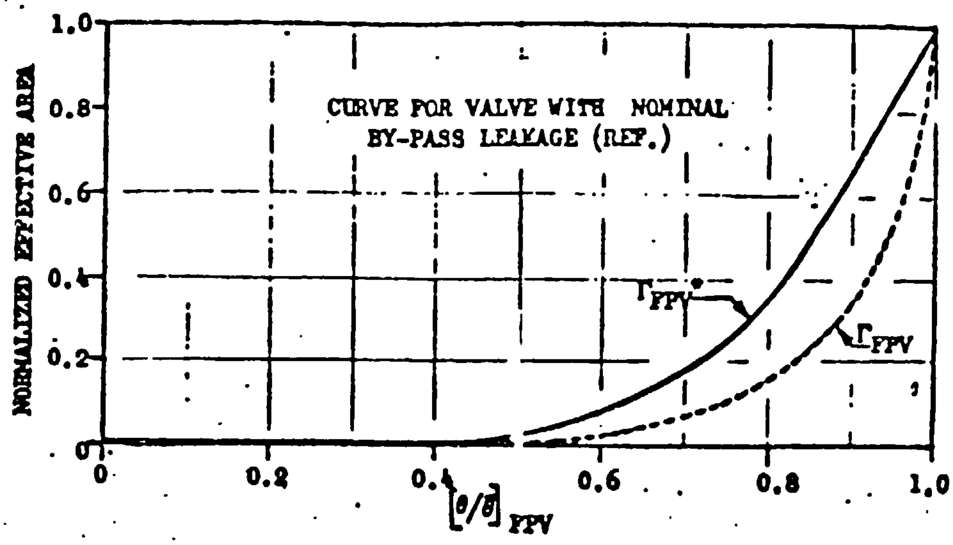
A resistance of 2.205×10^{-5} Sec^2/In^5 was used in series with RF_{CCV} values listed below to obtain Γ_{CCV}. A resistance of 1.3618×10^{-4} was used in series with RF_{CCV} values listed below to obtain Γ_{CCV}*.

$[\theta/\bar{\theta}]_{CCV}$	1000 RF_{CCV}	Γ_{CCV}	Γ_{CCV}*
1.0000	0.0000	1.0000	1.0000
0.9563	0.0173	0.7489	0.9420
0.9125	0.0434	0.5806	0.8708
0.8688	0.0860	0.4518	0.7829
0.8250	0.1524	0.3555	0.6870
0.7813	0.2422	0.2888	0.6000
0.7375	0.3820	0.2336	0.5127
0.6938	0.5891	0.1899	0.4333
0.6500	0.8961	0.1550	0.3632
0.6063	1.3206	0.1281	0.3057
0.5625	1.9055	0.1070	0.2583
0.5188	2.7345	0.0894	0.2178
0.4750	3.9210	0.0748	0.1832
0.4313	5.6980	0.0621	0.1528
0.3875	8.0138	0.0524	0.1293
0.3438	11.3647	0.0440	0.1088
0.3000	16.8862	0.0361	0.0894
0.2563	26.6630	0.0287	0.0713
0.2125	44.4762	0.0223	0.0553
0.1688	80.9009	0.0165	0.0410
0.1250	167.2343	0.0115	0.0285
0.0813	410.1394	0.0073	0.0182
0.0375	1186.7226	0.0043	0.0107
0.0052	1557.6401	0.0038	0.0093

– Coolant Control Valve Effective Area vs Position Characteristic

ATTACHMENT I

Figure 2



A resistance of 1.71875 x 10^{-4} Sec^2/In^5 was used in series with RF_{FPV} values listed below to obtain Γ_{FPV}. A resistance of 0.000860 Sec^2/In^5 was used with RF_{FPV} to obtain Γ_{FPV}*

$[\theta/\bar{\theta}]_{FPV}$	1000 RF_{FPV}	Γ_{FPV}	Γ_{FPV}*
1.0000	0.0000	1.0000	1.0000
0.9688	0.2441	0.6428	0.8826
0.9375	0.5721	0.4806	0.7750
0.9063	1.0373	0.3770	0.6733
0.8750	1.7632	0.2980	0.5726
0.8438	2.9811	0.2335	0.4732
0.8125	4.8906	0.1843	0.3867
0.7813	7.8665	0.1462	0.3139
0.7500	12.0122	0.1188	0.2584
0.7188	18.1261	0.0969	0.2128
0.6875	27.6590	0.0786	0.1737
0.6563	41.8487	0.0640	0.1419
0.6250	67.0422	0.0506	0.1125
0.5938	117.7405	0.0382	0.0852
0.5625	228.3827	0.0274	0.0613
0.5313	522.1774	0.0181	0.0406
0.5000	1094.5552	0.0126	0.0280
0.4688	3648.5732	0.0068	0.0154
0.4503	5043.4377	0.0058	0.0131
0.0880	5043.4377	0.0058	0.0131
0.0000	∞	0.0000	0.0000

– Fuel Preburner Oxidizer Valve Effective Area vs Position Characteristic

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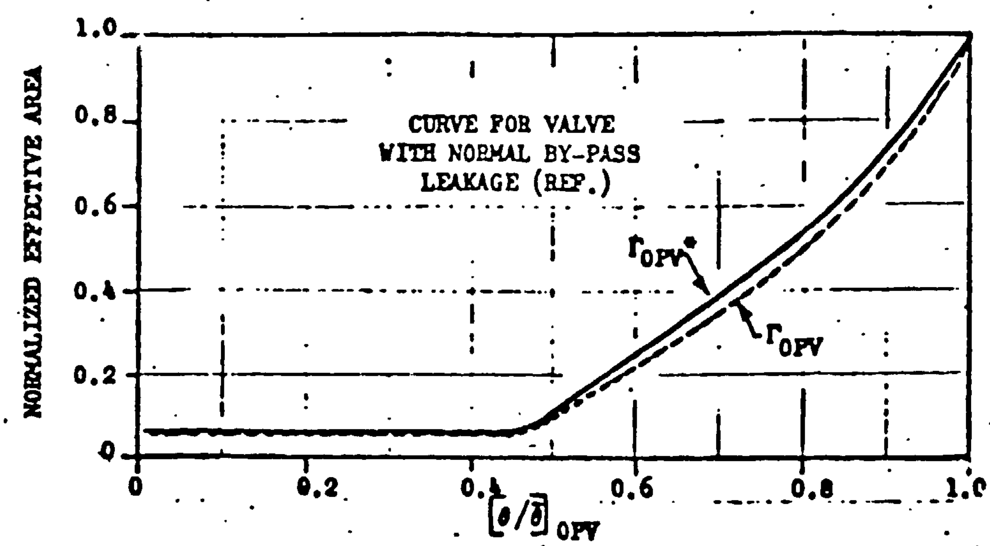
Figure 3



A resistance of 0.00204 Sec^2/In^5 was used in series with RF_{OPV} values listed below to obtain Γ_{OPV}^*.

$[\theta/\bar{\theta}]_{OPV}$	1000 RF_{OPV}	Γ_{OPV}	Γ_{OPV}^*
1.0000	10.26	1.00000	1.0000
0.9688	13.11	0.88494	0.9012
0.9375	16.33	0.75268	0.8184
0.9063	20.17	0.71339	0.7443
0.8750	24.76	0.64382	0.6776
0.8438	30.33	0.58171	0.6165
0.8125	37.18	0.52544	0.5601
0.7813	45.72	0.47380	0.5076
0.7500	56.59	0.42587	0.4581
0.7188	70.74	0.38092	0.4112
0.6875	89.65	0.33835	0.3663
0.6563	115.85	0.29764	0.3231
0.6250	153.80	0.25833	0.2810
0.5938	212.19	0.21993	0.2397
0.5625	310.08	0.18193	0.1985
0.5313	496.75	0.14374	0.1571
0.5000	937.19	0.10465	0.1145
0.4688	2460.56	0.06459	0.0707
0.4503	2618.31	0.06261	0.0685
0.0880	2618.31	0.06261	0.0685
0.0000	∞	0.00000	0.0000

- Oxidizer Preburner Oxidizer Valve Effective Area vs Position Characteristic

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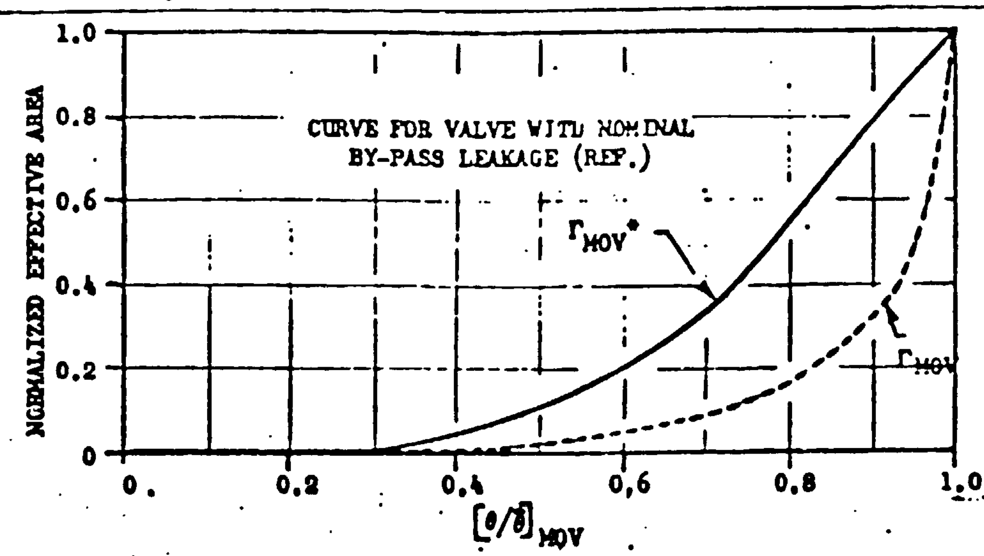
Figure 4



A resistance of 4.9508×10^{-5} Sec^2/In^5 was used in series with RF_{MOV} values listed below to obtain Γ_{MOV}. A resistance of 4.9508×10^{-5} Sec^2/In^5 was used in series with RF_{MOV} values listed below to obtain Γ_{MOV}*

$[\theta/\bar{\theta}]_{MOV}$	1000 RF_{MOV}	Γ_{MOV}	Γ_{MOV}*
1.0000	0.0000	1.0000	1.0000
0.9706	0.0062	0.5960	0.9428
0.9412	0.0148	0.4335	0.8775
0.9118	0.0244	0.3502	0.8185
0.8824	0.0377	0.2883	0.7535
0.8529	0.0566	0.2386	0.6831
0.8235	0.0829	0.1989	0.6115
0.7941	0.1242	0.1636	0.5339
0.7647	0.1790	0.1368	0.4655
0.7353	0.2608	0.1137	0.3995
0.7059	0.3586	0.0971	0.3483
0.6765	0.5016	0.0822	0.2997
0.6471	0.6824	0.0706	0.2601
0.6176	0.9387	0.0602	0.2238
0.5882	1.2987	0.0512	0.1916
0.5588	1.8086	0.0434	0.1632
0.5294	2.6280	0.0360	0.1360
0.5000	4.0420	0.0291	0.1100
0.4706	6.6806	0.0227	0.0862
0.4412	11.6485	0.0171	0.0650
0.4118	23.3579	0.0121	0.0460
0.3824	56.8137	0.0078	0.0295
0.3529	116.8515	0.0055	0.0206
0.3235	389.9630	0.0030	0.0113
0.0880	389.9630	0.0030	0.0113
0.0000	–	0.0000	0.0000

– Main Oxidizer Valve Effective Area vs Position Characteristic

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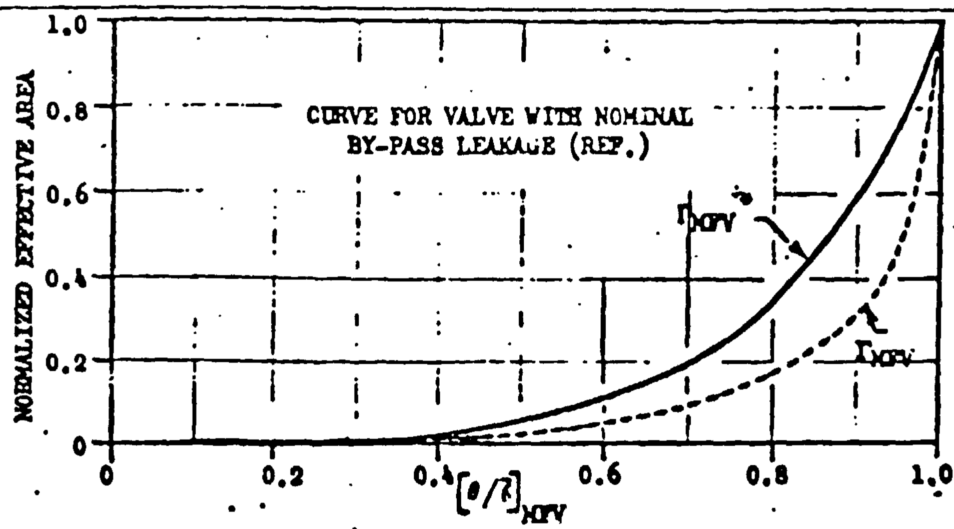
Figure 5



A resistance of 1.523 x 10^{-5} Sec^2/In^5 was used in series with RF_{MFV} values listed below to obtain Γ_{MFV}. A resistance of 1.523 x 10^{-5} Sec^2/In^5 was used in series with RF_{MFV} values listed below to obtain Γ_{MFV}*

$[\theta/\bar{\theta}]_{MFV}$	10000 RF_{MFV}	Γ_{MFV}	Γ_{MFV}*
1.0000	0.0000	1.0000	1.0000
0.9706	0.0062	0.5959	0.8430
0.9412	0.0148	0.4333	0.7121
0.9118	0.0245	0.3500	0.6191
0.8824	0.0377	0.2881	0.5364
0.8529	0.0567	0.2384	0.4601
0.8235	0.0831	0.1987	0.3936
0.7941	0.1245	0.1634	0.3301
0.7647	0.1797	0.1366	0.2795
0.7353	0.2620	0.1134	0.2344
0.7059	0.3606	0.0969	0.2013
0.6765	0.5048	0.0820	0.1711
0.6471	0.6877	0.0703	0.1472
0.6176	0.9476	0.0599	0.1258
0.5882	1.3136	0.0509	0.1071
0.5588	1.8338	0.0431	0.0908
0.5294	2.6736	0.0357	0.0753
0.5000	4.1318	0.0287	0.0606
0.4706	6.8157	0.0224	0.0472
0.4412	12.1364	0.0168	0.0354
0.4118	24.7647	0.0117	0.0248
0.3824	62.4854	0.0074	0.0156
0.3529	148.2311	0.0048	0.0101
0.3235	595.4925	0.0024	0.0051
0.0880	595.4925	0.0024	0.0051
0.0000	∞	0.0000	0.0000

– Main Fuel Valve Effective Area vs Position Characteristic